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Acoustic extinction in dense herring layers, measured from a bottom-mounted transducer

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Abstract

Herring is often found in dense aggregations or schools, and acoustic shadowing is thus a problem in acoustic survey estimates. Knowledge of the attenuated echo intensity in herring aggregations is essential for correcting the measured area backscattering coefficient for extinction. The attenuation is measured through the extinction coefficient (σ_e/σ_b), which can be found by analyzing the reduction in echo intensity from a reference target while different densities of fish are located between the transducer and the reference target. In this study, the transducer was bottom-mounted and the sea surface was used as a reference target. The paper will present new data on the extinction coefficient for herring, as well as its variability. This variability has further been used estimate the uncertainty in the correction algorithms for a typical herring survey.

Keywords: Herring surveys, extinction coefficient

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Introduction

Acoustic shadowing has been well proven both by recordings in sea pens as well as *in situ* experiments (e.g. Røttingen 1976, Furuzawa et al. 1984, Armstrong *et al.* 1989; Appenzeller and Leggett, 1992; Burczynski *et al.* 1990). Røttingen (1976) conducted an experiment with saithe (*Pollachius virens*) and sprat (*Sprattus sprattus*) in sea pens. Foote (1978) analysed the results theoretically. This experiment showed that increasing fish density was not linear to received echo intensity. Above a certain density, the echo intensity increased less than the fish density until a maximum echo intensity was reached. With still increasing fish density the echo intensity decreased.

The fish schools ability to attenuate the sound depends on the respective specie's extinction coefficient (σ_e). This has normally been measured together with the backscattering cross-section (σ_b) in the ratio σ_e/σ_b called the extinction coefficient, which is a dimensionless value. The acoustic effects of shadowing have mainly been measured by the reference target technique (e.g. Toresen, 1991, Armstrong *et al.* 1989; Olsen, 1986). When a transmitted signal penetrates a dense fish aggregation, the fish layer reduces the sound intensity. This leads to a lower sound intensity reaching the reference target, ignoring loss caused by range and beam pattern. The signal will also be attenuated on its way back to the transducer causing a further decrease in the sound intensity (Figure 1). Thus, there is a two-way transmission loss. The reduction in the echo intensity from the reference target caused by the fish is then a measurement of the shadowing effect. Compensation of the lost part of the signal caused by the attenuation is necessary (Foote, 1983; MacLennan, 1990).

Two types of reference targets have been used to find the degree of shadowing in aggregations of fish by the reference target technique. Olsen (1986) and Armstrong *et al.* (1989) used a steel sphere with known acoustic properties as a reference target. At first the target strength was calculated when there were no fish between the sphere and the transducer, and later when a dense aggregation of fish was present. In the experiment by Olsen the echo intensity of the reference sphere was reduced by up to 85 %. Toresen (1991), Foote *et al.* (1992) and Foote (1999) used the bottom as a reference target. When using this method it is very important that the bottom is flat, so that the mean echo energy from the bottom is fairly constant. This backscattering from the bottom is a function of the backscattering from the water column, in other words a function of the shadowing effect from fish schools. By making a linear regression of s_A values of the bottom on the water column, the extinction coefficient can be found by algorithms (Foote, 1999).

In this paper the method for using a bottom-mounted transducer to measure extinction is described, by using the surface as a reference target. The various problems and possibilities with this system are discussed in a separate paper (Utne and Ona, 2006), while the main results are presented here.

Theory

In this study the transducer is bottom-mounted facing upwards. The received echo energy from the fish layer will be compared against the surface echo energy, after losses due to beam pattern and range are compensated for. Two slightly different approaches have been for estimating the extinction coefficient: one by Zhao and Ona (2003) and a second one described by Foote (1990), and further used in Foote *et al* (1992) and Foote (1999).

By using the method described by Zhao and Ona, it is essential to find the shadowing coefficient β (Zhao *et al.*, 1993), which is a dimensionless quantity $\in$ [0,1].

$$\beta = \frac{s_{A,S0} - s_{A,S}}{s_{A,S0}} \quad (1)$$

where $s_{A,S}$ and $s_{A,S0}$ are the area backscattering coefficient of the reference target with and without fish intervening the transmitted signal. An important criterion for using this approach is a stable initial backscattering coefficient from the reference target.

β can be further used to estimate the extinction coefficient by the following equations;

$$\beta' = \left(\frac{1852^2}{2}\right) \times \beta \quad (2)$$

$$\beta' = \gamma \times s_{\tilde{A}} + \varepsilon \quad (3)$$

where ε is the normal distributed error term and γ is a constant.

In the second approach, (Foote *et al.* 1992) used directly the linear relationship between the received echo intensity from the fish layer ($s_{A,F}$) and from the surface ($s_{A,S}$). Then $s_{A,S}$ can be expressed by;

$$s_{A,S} = \alpha + \beta s_{A,F} \quad (4)$$

Where α and β are the regression coefficients, which are used to find the extinction coefficient by the following equation:

$$\frac{\sigma_e}{\sigma_b} = \frac{-1852^2 \times \beta}{(2 \times \alpha)} \quad (5)$$

Uumati (2004) compared these two methods, and found only small differences in the results although the backscattering coefficient from the bottom varied. The main advantage of the method by Zhao and Ona is its possibility to pool or compare data recorded with different reference targets, while the method by Foote (1990) has the advantage of not needing to know the initial backscattering coefficient of the reference target. Algorithms for correcting the data when the extinction coefficient is known, have been proposed by Foote (1990) and refined by Zhao and Ona (2003), and will not be dealt with in this paper.

The backscattering from the sea surface is affected by several factors. The echo strength is influenced by entrapped air bubbles just beneath the surface, and by roughness on the surface (Urick, 1967). When there is a calm surface with none or only very low waves, the direction of the backscattering from the surface should be equal to the incident wave, giving perfect reflection when the transducer faces directly up against the surface (MacLennan and Simmonds, 1992). On the other hand, if there were high waves at the surface, the incident wave will be scattered in several directions. There would then be a reduction in the mean $s_{A,S0}$.

An equation for the surface scattering strength (dB) is given by Chapman and Scott (1964), as they reduced the results from Echart (1953) to practical form.

$$Ss = -10 \log 8\pi \alpha^2 - 2.17 \alpha^{-2} \cot^2 \theta \quad (6)$$

θ - Grazing angle in degrees

α^2 - Mean-square slope of surface wave

By empirical observations Cox and Munk (1954) found the following relationship between mean-square slope and wind speed.

$$\alpha^2 = 0.003 + 5.12 * 10^{-3} W \qquad (7)$$

W - wind speed (m s^{-1})

These equations give an indication of the backscattering strength of the surface, although some deviation from the theory must be accepted (Gensane, 2002). From these equations it is possible to compute approximately how the surface backscattering, expressed through $s_{A,S0}$ should vary with wind speed, assuming that the surface waves are completely correlated with wind speed.

Material and Methods

On 23 October 2002 a pressure-stabilized transducers were mounted on the bottom in the opening of Ofotenfjorden, which is an extension of Vestfjorden. These fjords are located in the northern part of Norway (68°37´ North, 16°15´ West), west of the city Narvik (Figure 2a,b). Ofotenfjorden was used due to its narrow opening, and the amount of NSS-herring that each year uses the fjord as an over-wintering area. The transducer was positioned at the bottom at around 400 m.

The echo sounder was mounted into a steel framework, which was built on a concrete base (Figure 2c). The transducer was connected to a 38 kHz general-purpose transceiver (GPT), which was linked to an Ethernet network. This controlled an inclinometer, which monitored the transducer orientation. A gimbal mounting ensured that the transducer faced directly up against the surface regardless of the inclination of the seafloor. The split beam transducer, a Simrad ES38DD, with modified element configuration to give approximate opening angles of 23 x 7°, was on short cable directly coupled to the EK60 transceiver unit in the same mounting. A cable stretched from land supported the system with electrical power and optical communication. Total weight of the construction was about 500 kg in air, and about 350 kg in water. This weight was necessary to ensure that the framework remained stable at varying current directions and velocities. All signals received by the echo sounder were sent through the cable to a land station where it was stored on a hard drive continuously.

Due to the great depth at which the transducer was positioned, it was not possible to do a proper calibration according the standard calibration procedure (Foote *et al.*, 1987). However, when measuring the extinction coefficient there is no need for calibration, as long as the relative measures of echo energy are accurate. Later, and after these measurements were finished, a challenging calibration was finally conducted using a remotely operated vehicle (Patel et al. 2005) with good results.

To reduce the ping-to-ping variation and to enable the analysis for longer time periods, the average of 100 pings was found to be sufficiently stable (Utne and Ona 2006), and used for the subsequent analysis. Investigations of how the wind and waves affected the surface echo was also made (see Utne and Ona 2006), and optimal periods for low variability were selected from wind data recorded on a lighthouse outside the fjord. These investigations also included possible effects of nearfield reverberation, and median filtering used for removing interference from passing vessels using 38 kHz echo sounders.

After filtering, the procedure of data collection when herring aggregations were present, involved pair-wise recording of the area-backscattering coefficient from the reference target and the water column (MacLennan *et al*., 1990; Toresen, 1991; Foote *et al.,* 1992. Thus, two parallel area-backscattering coefficients are recorded in the same time period. The layers must be wide enough to include the entire target in question, but small enough to exclude unwanted targets. To find the minimum range that included the whole surface echo, the effect of different ranges were visually observed in ER60. The range to scrutinize for the surface echo was set to 397 - 427 meters, which surely engulfed the entire surface echo independent of tide. $s_{A,F}$ was set to 5 - 397 meters (Figure 3) .

The biological data was taken from the survey of NSS herring, in December 2002, when 72 trawl hauls was conducted, using a pelagic herring trawl with a multi sampler device was used (Engås *et al.*, 1997). The location closest to the transducer is Barøya where over 47% of the herrings were sampled. 528 individuals were age measured, and 6161 individuals were length and weight measured. The composition of age classes revealed that the 1998-year class was dominating, although other year classes were also represented. Mean length with standard deviations of the herring were 33.7±2.4 cm, and mean weight was 311±67 g.

Results

All the treated data were recorded in November or December 2002, in the peak of the wintering process. 8 November - 31 December 2002, were then analysed separately. Four days in November and almost all the days in December had high enough herring densities to measure extinction. To prevent recordings of $s_{A,S}$ to influence the regression line and thereby the estimated extinction coefficient in times with very low fish density, all pings with recorded $s_{A,F}$ less then 10 000 were excluded from the data set used in the linear regression. Stable wind condition was defined as wind speed between 3 – 10 m s^{-1}, with variation during the day. If the wind speed was stable within the limits except for a very short period, the data was still found acceptable.

A special pattern is seen on 1 December (Figure 5) and 4 of December where it seems that the extinction coefficient changes throughout the day. These days have many recordings with $s_{A,S}$ around 10 million, where the recorded $s_{A,F}$ varies from approximately 200 000 – 800 000 which gives an extinction coefficient close to zero. The wind conditions were acceptable with speed around 6-7 m s^{-1} from west. This is equal to the conditions on 23-24 December, which had normal results. The pattern did not clearly depend on light conditions, mean depth, or vertical spread of the herring layer. These days were excluded from the data set due to this pattern. The 26 December gave a negative extinction coefficient even though the wind conditions were acceptable, and was thus excluded.

The main results are presented in Table 1. Example echograms for 4 full days are shown in Figure 4 showing the varying density, but also the strong vertical migration pattern. The mean extinction coefficient with corresponding standard deviation was 2.46±0.41. From the extinction coefficients were σ_e calculated, and the mean and its standard deviation were estimated to be 22.8±3.8 cm^2. The fish density then needed for complete shadowing is $s_{A,F} \approx$ 697 000 [m^2 nmi^{-2}].

Diel variation

Diel variation has been proposed as a plausible reason for the variability in the extinction coefficient (Foote et al., 1992). It is known that herring perform vertical migration triggered by light (Huse and Korneliussen, 2000). Light conditions for each date was found on Internet, at U.S. Naval Observatory. The output was start and end of civil twilight, as well as sunrise and sunset.

Two time-periods were used in this analysis due to their relative stable wind conditions and over all large values of $s_{A,F}$. The periods were 2-7 December and 23-25 December 2002, with 4 December excluded. The system setup was well suited to investigate if there was a diel variation in the extinction coefficient. Although it would be more precise to use from sunrise to sunset, which was done in Korsbrekke and Nakken (1999), this was not possible due to the very short period with sunlight in December. In most of the period the sun did not raise above the horizon at all, and the time of civil twilight had to be used. Daytime was defined as the period from start till end of civil twilight. Of course, this method ignored differences in light condition between sunny and rainy days.

The results for daytime are given in Table 2, and for nighttime in Table 3. There was a significant difference between the results for night and day (p=0.03), and between night and the general results (p=0.03). The mean extinction coefficient with complementary standard deviation were 2.74±0.66 for daytime and 1.91±0.67 for night time, respectively.

The effect of fish depth distribution on extinction

Vessel avoidance is a well-known source of error in acoustic measurements (Aglen, 1994; Vabø *et al*., 2001), especially in pelagic spices like herring. This experiment setup is assumed to not affect the herring, and is therefore well suited to investigate if mean fish depth and/or how the vertical distribution of the herring in the water column affect the extinction coefficient.

First, any depth differences in the extinction coefficient were investigated. Two short periods with relative equal and stable wind conditions were selected, namely 5-7 December, and from 18.00 on 22 December to the end of the 25 December. The data were median-filtrated and pooled before they were divided into six groups based on the mean depth of which the herring was located. A linear regression was made for each group. Secondly, the total vertical spread of the fish was investigated. The same time period was used as for the study of mean depth of the fish. The two depths where 10 % and 90 % of the fish was located above were found, and the difference between these depths was calculated. The data was then divided into five groups based on the vertical spread of the herring layer.

The results from the investigation with varying mean depth show a clear trend of an increasing extinction coefficient with increasing depth (Table 4, Figure 6). The result from depth 0-100 meters is based on a small dataset, and is therefore a rather unstable, and not very accurate result. Except for the result from depth 0-99 meters there is no overlap of the confidence intervals. A significant correlation coefficient of 0.97 between the mean depth and the extinction coefficient was found (p=0.0012). The results from the investigation of fish distribution with varying vertical spread are given in Table 5. There was not a significant difference between the extinction coefficient and the vertical spread (p=0.1450). There is however a trend of a decreasing extinction coefficient with increasing spread in the water column, with the vertical spread of 150-200 meters as an exception.

Discussion

Several projects that calculated the extinction coefficient for different species have been conducted. The estimated value for herring has varied from 1.4 to 5 (Røttingen, 1976; Olsen, 1986; Armstrong *et al.*, 1989: MacLennan *et al.*, 1990; Foote *et al.*, 1992; Foote, 1999). MacLennan *et al.* (1990) explains this large variation with the stochastic nature of both σ_b as well as σ_e. Uumati (2004) found an extinction coefficient of 0.627 for sardine, which agreed well with the estimates for cod of (1.1) by MacLennan *et al.* (1990), and saithe (0.77) by Røttingen (1976). There can be reasons to doubt the similarities of the extinction coefficient between gadoids and clupeoids fishes due to the variation in the results from the different experiments. Since herring and sardine are both physostome clupeoids, it would be not unreasonable to assume that these species have quite similar extinction coefficients. Uumati's work suffered from the possibility to average pings due to the small amount of pings used for each estimate of the extinction coefficient. The stochastic nature of the received echo from the reference target strongly influenced the result.

The mean value of the extinction coefficient in this investigation was 2.46±0.41, which gives a measured σ_e of 22.8 cm^2 for 33.7 cm herring if the presently used target strength relationship for herring is used. This is in close accordance with the results from Foote (1999), based on measurements from the vessel. He found an extinction coefficient of 2.41±0.33, and estimated σ_e to be 22.7 cm^2 for 33.9 cm herring. This result is at present assumed to be close to the correct value, and is used in computing actual stock size from survey data. Foote's experiment was conducted from a moving vessel, and the bottom was used as a reference target. This indicates that although neither the bottom nor the surface is a perfect reference target, the stability of the reference target will not affect the measurements to a large extent. This requires that the used data are properly selected so that the reference target variability is held at a minimum, and that a large data set is selected in order to minimize the stochastic nature of measured σ_b and σ_e. It also indicates that whether the fish is ensonified from the ventral of the dorsal side first does not affect the extinction coefficient. This is obvious according to the theory, since the sound is reflected from the reference target and the fish is ensonified from both sides independent of the transducer's position.

The variability in the measured extinction coefficient in the investigation is almost identical to the material analysed by Foote (1999). He suggested that the altered fish behaviour due to horizontal migration could be the reason for this variability. The herring normally enters the fjord in November, remains more or less stationary in December, and starts leaving the fjord in January (Røttingen *et al*,. 1994). Since Foote's investigations were conducted throughout January and this investigation was performed throughout December, it is not likely that horizontal migration explain the variation in the extinction coefficient. Since the extinction coefficient is so dependent of the depth at which the fish is located in, variation in the results will always be present in general extinction studies, even with a perfect reference target.

The orientation and state of the swim bladder is well known to have a large effect on σ_b (e.g. Nakken and Olsen, 1977; Foote and Nakken, 1978). Foote *et al.*, (1992) suggests that these factors affect σ_e less than they affect σ_b, while Foote (1999) later stated that σ_b and σ_e most likely will have an equal response to changes in swim bladder orientation and condition.

An obvious depth dependence on σ_b has been proven by Gorska and Ona (2003a; 2003b). The backscattering from the herring can be divided in two parts, backscattering from the swim bladder ($\sigma_{b,sb}$) and backscattering from the rest of the fish ($\sigma_{b,f}$). The ratio $\frac{\sigma_{b,f}}{\sigma_{b,sb}}$ is much higher when the herring is located in deeper waters compared to herring close to the surface due to an altered orientation of the fish and to swim bladder compression.

The condition factor is known to affect the buoyancy of the fish (Ona, 1990), but the small, about 1 %, decrease in fat content from December to January (Røttingen *et al.*, 1994) is not expected to have a large effect on the scattering properties of the herring. The investigation of possible differences in the extinction coefficient with depth, vertical distribution or light conditions is actually three ways of investigating the same issue. During daytime, the herring is schooling at deeper water to avoid visual predators (Huse and Ona, 1996; Huse and Korneliussen, 2000). The herring is generally more dispersed at night, and moves higher up in the water column. The migration is mainly done during dusk and dawn. In this study, daytime was defined as times with civil twilight. This is an oversimplification necessary due to the lack of proper daylight.

The use of a bottom-mounted transducer is a good way to investigate diel variation, and has been done for biomass investigation before (Fabi and Sala, 2002; Axenrot *et al.*, 2004). The possible difference between night and day for the extinction coefficient has earlier been discussed in several papers (e.g. Foote *et al.*, 1992; Foote, 1999; Zhao and Ona, 2003). Foote *et al.* (1992) separated the result into day and night, but there were too few estimates of the extinction coefficient to make any general conclusion. In this study, a difference between day and night for the extinction coefficient has been found and proved statistically. The large variation within each group is probably due to the rather small data set used for each estimate of the extinction coefficient. This may also be the reason why there was a negative extinction coefficient on the 26th of December.

Olsen (1986) took photographs of the fish during his investigation of the shadowing effect in herring schools. Based on these photos, he suggested the altered tilt angle is the reason for the difference in attenuation of sound in fish schools. Orlowski (2000) found a decrease in σ_b at daytime for pelagic Clupeid, mainly herring. The results showed that the decrease in σ_b was correlated the mean depth of the fish due to its diel vertical migration. Since herring lacks the ability to regulate the volume of the swim bladder, they must swim with a positive tilt angle at deeper water to avoid sinking either by continuously swimming or by the kick-and-glide tactic (Huse and Ona, 1996). Thus, the herring has a larger spread of orientations at daytime when they are hibernating at deep water. If changing the man tilt angle and spread are the reasons for the observed difference in σ_e/σ_b, it is clear that σ_e must be less sensitive than σ_b to swim bladder state, indicating that other parts of the fish is contributing significantly to the attenuation. It can then be concluded that the depth at which the fish is located explains the variation in the extinction coefficient. This has been debated in several papers, as discussed above, but has now been proven. This is probably also the reason for a significant difference between the results for day and night, and the trend of a decreasing extinction coefficient when the fish are more vertically spread in the water, compared to very dense layers which are normally found close to the surface or the bottom.

The reason for the special pattern seen on the 1 and 4 December with a rapidly changing extinction coefficient with time, independent of depth and spread of the fish layer, is uncertain. It is also possible that this phenomenon is occurring other days as well, though in smaller scale, but still affecting the results. Since tilt angle and swim bladder state most likely affects the extinction coefficient, it is possible that some unknown behaviour of the fish can give these results. A further explanation will not be given in this paper.

The results presented in this paper clearly show the need to correct for extinction in biomass measurements of herring. Since the extinction coefficient is changing, the correction factor should be adjusted according to the depth the fish is located at, and that the different extinction coefficients should be applied for day and night. Generally, the correction will increase the total biomass of wintering herring by 1 – 8%. Methods for of correcting the herring survey data, also including the uncertainty in extinction is made by Aldrin *et al*. (2006).

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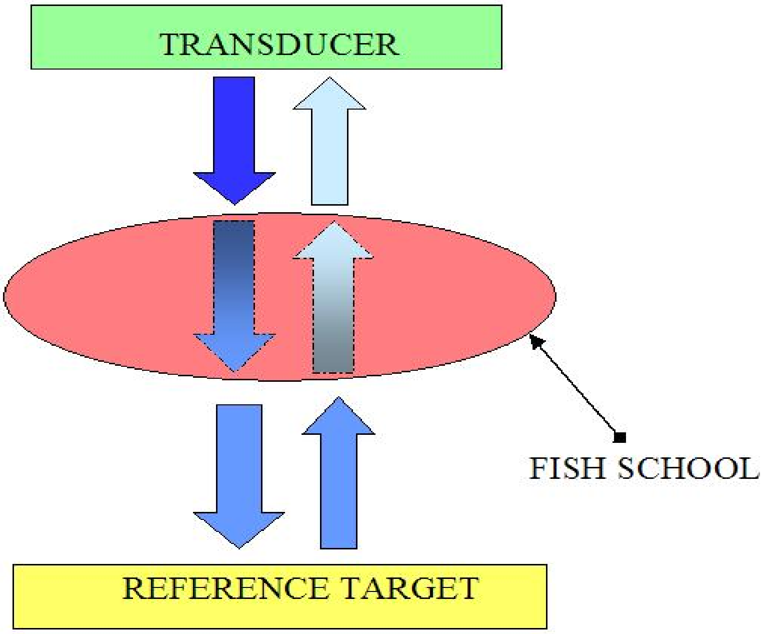

Figure 1. Scheme of the reference target technique for measuring acoustic extinction. The reduction in sound intensity is shown by the lighter colors in the arrows.

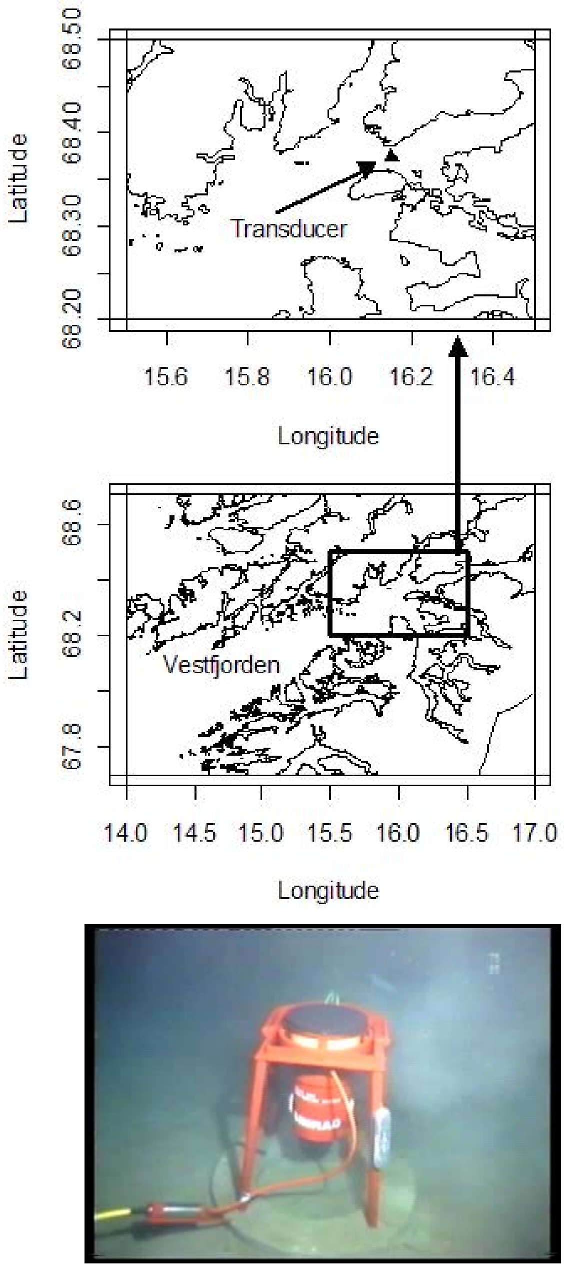

Figure 2. Transducer position in the intersection between Vestfjorden and Ofotfjorden, with picture of transducer platform.

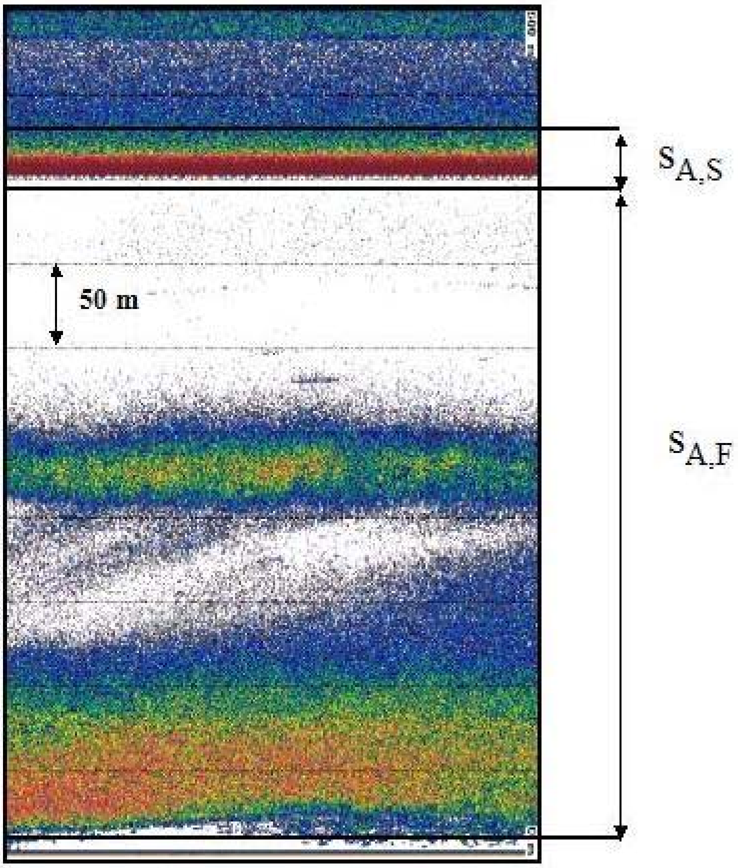

Figure 3. ER60 echogram taken in December 2002, showing the range and boundaries of $s_{A,S}$ (397-427m for the transducer) and $s_{A,F}$ (5-397m from the transducer).

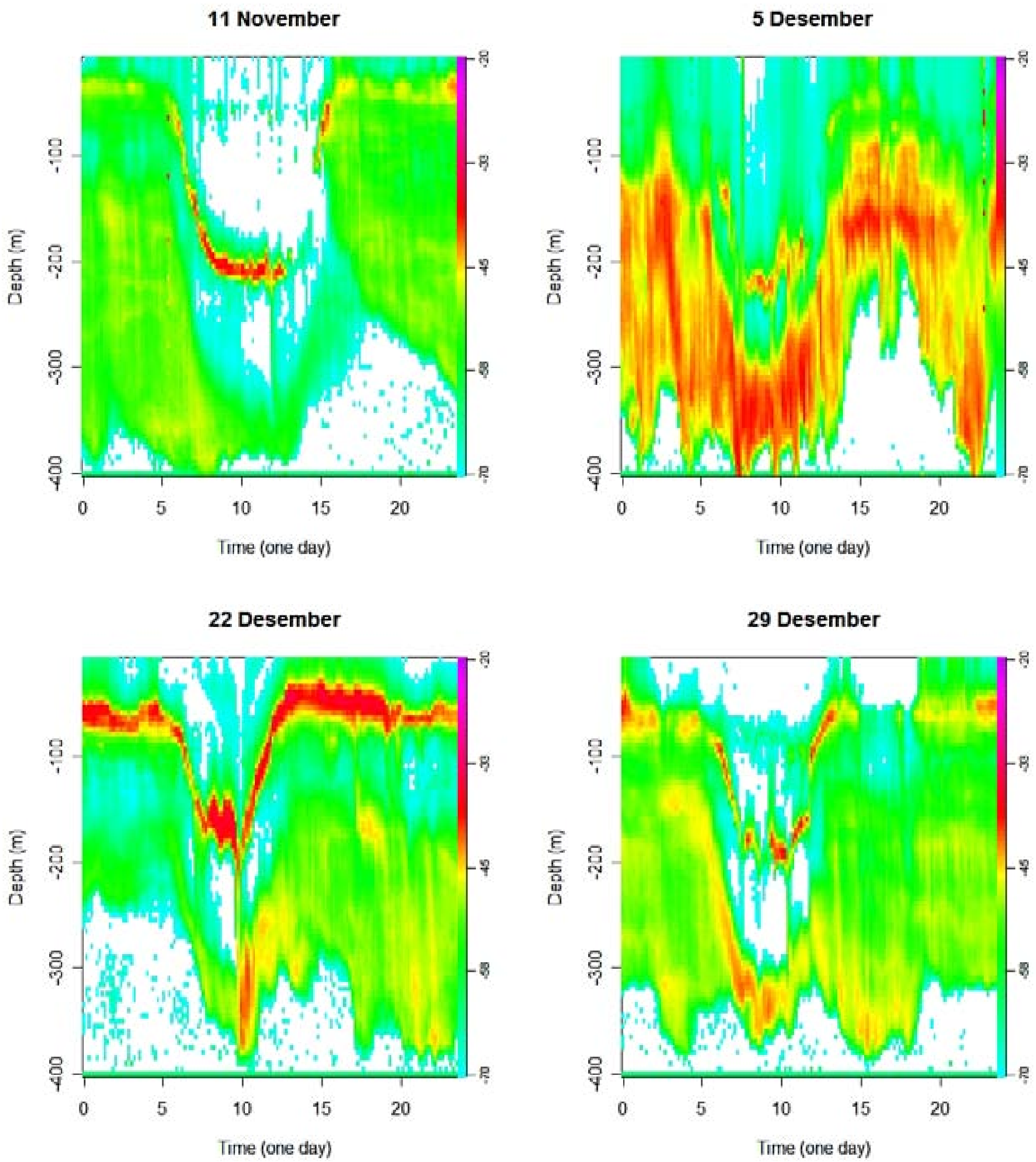

Figure 4. Example echograms over 24 hours, four days. Herring echo energy is expressed as by S_V (dB ref $1m^{-1}$), right side.

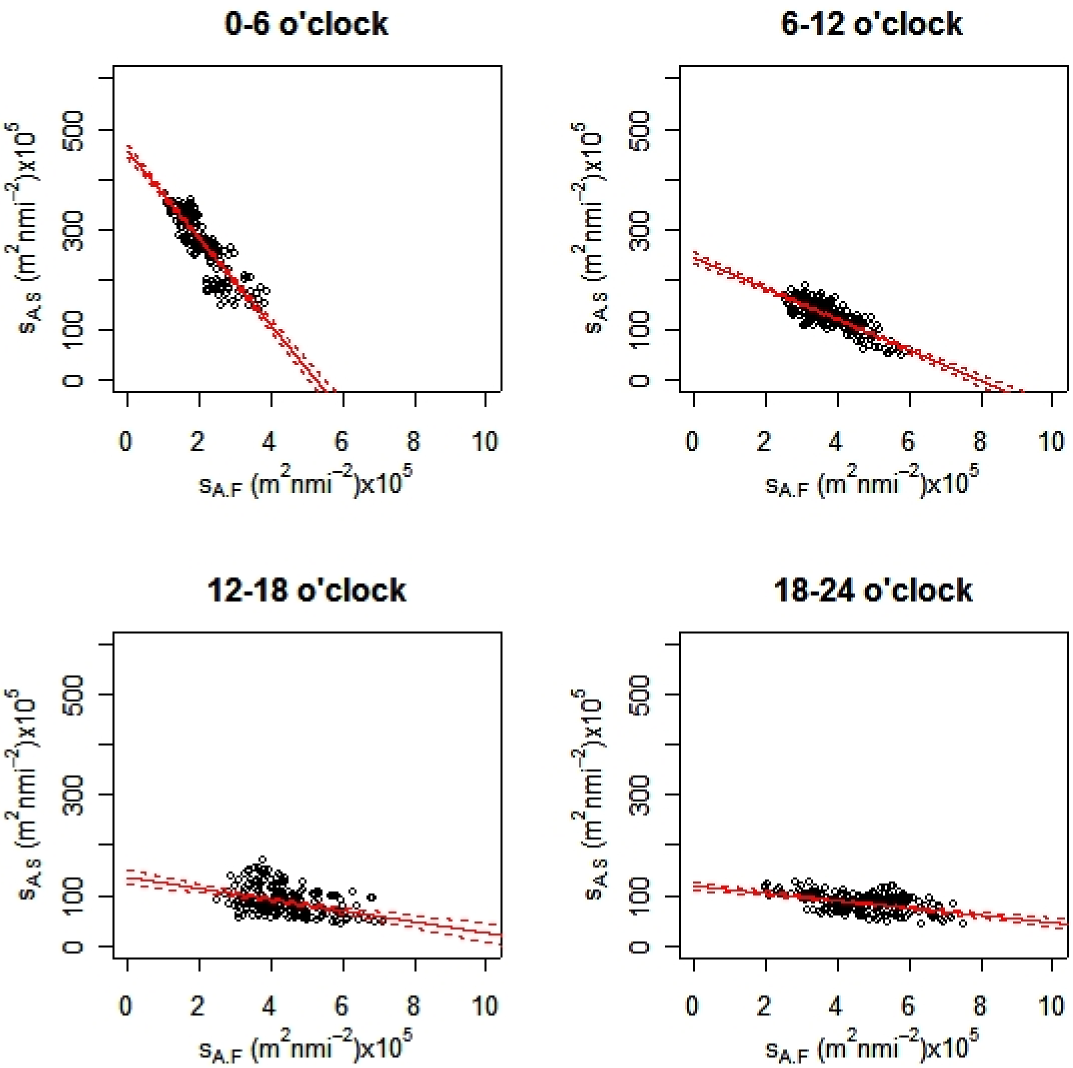

Figure 5. Scatter diagrams with linear regression analyses for the surface $s_{A,S}$ on the backscattering coefficient for fish $s_{A,F}$. Data are presented from 1 December 2002.

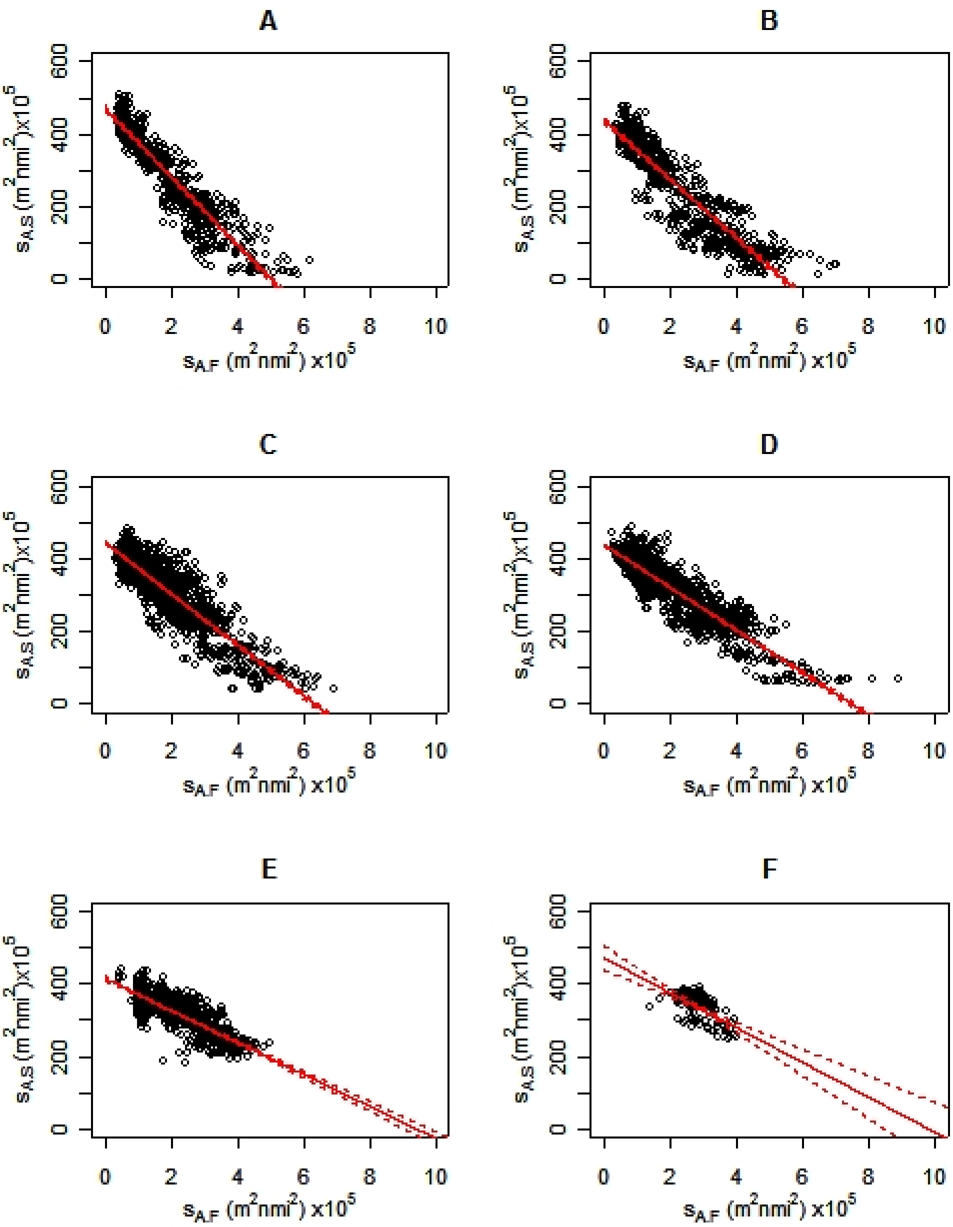

Figure 6. Linear regression of $s_{A,F}$ against $s_{A,S}$ with its corresponding confidence intervals, for the mean depth of the herring concentration. Each graph is from one depth group. A) 300-400 m. B) 250-300 m. C) 200-250 m. D) 150-200 m. E) 100-150 m. F) 0-100 m.

Table 1. Main results of the linear regression of $s_{A,S}$ on $s_{A,F}$, included standard error of the regression (S.E), estimated value of the ratio σ_e/σ_b with 95 % confidence interval, assumed value of σ_b (cm^2), computed value for σ_e (cm^2). p<0,0001 for all the linear regression results.

Date	α	β	S.E	N	σ_e/σ_b	(σ_e/σ_b)-	(σ_e/σ_b)+	σ_b	σ_e
10.Nov	45729800	-71.59	2606000	507	2.68	2.51	2.86	9.27	24.84
11.Nov	46000800	-54.02	3248000	527	2.01	1.64	2.38	9.27	18.63
12.Nov	48831700	-75.53	4865000	575	2.65	2.43	2.87	9.27	24.57
13.Nov	45296200	-77.8	3063000	470	2.95	2.70	3.19	9.27	27.35
02.Dec	46791400	-71.85	4637000	968	2.63	2.47	2.79	9.27	24.38
03.Dec	43593600	-64.11	5295000	630	2.52	2.47	2.57	9.27	23.36
05.Dec	29508000	-40.31	5726000	860	2.34	2.24	2.44	9.27	21.69
06.Dec	41075500	-61.10	5372000	863	2.55	2.44	2.66	9.27	23.64
07.Dec	45261000	-60.28	4609000	863	2.28	2.21	2.35	9.27	21.14
13.Dec	41943400	-65.24	4483000	599	2.67	2.59	2.74	9.27	24.75
15.Dec	43302030	-53.43	3304000	863	2.12	2.07	2.17	9.27	19.65
23.Dec	39535800	-38.09	3284000	863	1.65	1.52	1.78	9.27	15.30
24.Dec	41578900	-44.23	3263000	863	1.82	1.67	1.98	9.27	16.87
25.Dec	46819800	-83.58	3129000	863	3.06	2.87	3.24	9.27	28.37
28.Dec	40147600	-60.48	3047000	863	2.43	2.58	2.74	9.27	22.53
29.Dec	38515900	-66.85	3953000	863	2.97	2.78	3.18	9.27	27.53

Table 2. Results of the linear regression of sA,S on sA,F for daytime, included standard error of the regression (S.E), estimated value of the ratio σe/σb with 95 % confidence interval, assumed value of σb (cm2) and computed value for σe (cm2). p<0.0001 for all the linear regression results.

Date	α	β	S.E	N	σ_e/σ_b	$(\sigma_e/\sigma_b)-$	$(\sigma_e/\sigma_b)+$	σ_b	σ_e
02.Dec	28895200	-46.14	2554000	240	2.74	2.66	2.81	9.27	25.40
03.Dec	46431800	-79.86	3537000	148	2.95	2.87	3.03	9.27	27.35
05.Dec	19526500	-27.82	3178000	202	2.44	2.26	2.60	9.27	22.62
06.Dec	25261300	-21.65	3739000	204	1.47	1.04	1.83	9.27	13.63
07.Dec	44583300	-79.01	3940000	202	3.04	2.87	3.12	9.27	28.18
23.Dec	39992400	-54.41	2291000	184	2.33	2.19	2.47	9.27	21.60
24.Dec	45681300	-94.04	2056000	184	3.53	3.32	3.74	9.27	32.72
25.Dec	49310300	-98.29	3233000	184	3.42	2.86	3.95	9.27	31.70

Table 3. Results of the linear regression of sA,S on sA,F for night time, included standard error of the regression (S.E), estimated value of the ratio σe/σb with 95 % confidence interval, assumed value of σb (cm2) and computed value for σe (cm2). p<0,0001 for all the linear regression results.

Date	α	β	S.E	n	σ_e/σ_b	$(\sigma_e/\sigma_b)-$	$(\sigma_e/\sigma_b)+$	σ_b	σ_e
2-3.Dec	30674100	-33.989	3868000	730	1.90	1.82	1.97	9.27	17.61
3-4.Dec	44697200	-66.921	4621000	470	2.57	2.49	2.64	9.27	23.82
5-6.Dec	39031100	-54.021	4980000	659	2.37	2.26	2.48	9.27	21.97
6-7.Dec	39977300	-42.822	3348000	660	1.84	1.74	1.92	9.27	17.06
22-23.Dec	36816800	-18.348	3117000	680	0.85	0.73	0.98	9.27	7.88
23-24.Dec	39639200	-29.214	3333000	679	1.26	1.10	1.43	9.27	11.68
24-25.Dec	44813800	-68.227	2809000	679	2.61	2.33	2.88	9.27	24.19

Table 4. Results of the linear regression of sA,S on sA,F for different depths in meters, included standard error of the regression (S.E), estimated value of the ratio σe/σb with 95 % confidence interval, assumed value of σb (cm2) and computed value for σe (cm2), p<0,0001 for all the linear regression results.

Mean depth	**α**	**β**	**S.E**	**N**	**σ_e/σ_b**	**(σ_e/σ_b)-**	**(σ_e/σ_b)+**	**σ_b**	**σ_e**
0-100	47138700	-48.06	3003000	110	1.78	1.43	2.03	9.27	16.50
100-149	41542900	-44.11	3100000	765	1.82	1.75	1.89	9.27	16.87
150-199	43771480	-58.48	3549000	1534	2.29	2.25	2.33	9.27	21.23
200-249	44558860	-70.35	4175000	1558	2.71	2.66	2.76	9.27	25.12
250-299	43616900	-80.72	5265000	751	3.17	3.11	3.24	9.27	29.39
301-400	47182100	-94.16	4687000	690	3.42	3.37	3.49	9.27	31.70

Table 5. Results of the linear regression of sA,B on sA,F for the different vertical spread in distribution of the fish in the water column, included standard error of the regression (S.E), estimated value of the ratio σe/σb with 95 % confidence interval, assumed value of σb (cm2), computed value for σe (cm2). p<0,0001 for all the linear regression results.

Vertical spread	α	β	S.E.	N	σ_e/σ_b	$(\sigma_e/\sigma_b)-$	$(\sigma_e/\sigma_b)+$	σ_b	σ_e
>100	45857400	-72.589	5484000	1085	2.71	2.64	2.79	9.27	25.12
100-150	43031400	-62.975	5342000	1514	2.51	2.45	2.57	9.27	23.27
150-200	44166900	-74.192	5517000	1038	2.88	2.82	2.94	9.27	26.70
200-250	43501100	-56.687	3643000	1274	2.23	2.16	2.31	9.27	20.67
250>	41893500	-49.954	3243000	498	2.04	1.92	2.17	9.27	18.91